A GRANITE-GNEISS IN CENTRAL CONNECTICUT

THE granite-gneiss[1] to be described occurs on both sides of the Connecticut River, some five miles east of Middletown. It cuts the schists of the eastern crystalline area of Connecticut, a short distance east of their contact with the Triassic sandstone. Its distribution is shown on the accompanying map (Fig. 1).[2] It forms an oval area in the mica schist, and, at its northern end, is continued northward by a series of beds varying from a few inches to many feet in thickness, lying parallel to the enclosing schists. The largest of these is a direct continuation of the main granite-gneiss mass, and all are probably parts of the same intrusion. As the distance from the main area increases, these beds gradually thin out and disappear from the schists.

The only previous work on the geology of this region is that of Percival,[3] who recognized this granitic rock only on the east side of the river, and united that part of it with a large mass of granitic-gneiss to the north, with which it is probably not connected. He does not consider the origin of any of the gneisses. It has not been possible to use Percival's results except in a general way, and the work done in this region by the writer is essentially *de novo*.

The rock is a medium to fine-grained biotite-gneiss. The color varies from white or light gray to dark gray, according to the amount of biotite. In a few cases the rock is almost or quite massive, but usually it is well foliated. The granite-gneiss is cut by several sets of joint planes, of which one set is nearly

[1] In this paper a gneiss of granitic composition and of unknown origin is called a granitic gneiss; if of igneous origin, a granitic gneiss. See C. H. GORDON in Bull. Geol. Soc. America, Vol. VII, p. 122.

[2] That portion of the western boundary of the granite-gneiss north of the river is largely covered by river terrace, and for about a mile along the eastern border, near Great Hill pond, outcrops are rare. With these two possible exceptions, the "supposed boundary," so-called, is believed to be very nearly the true boundary.

[3] J. G. PERCIVAL: Report on the Geology of Connecticut. 1842, pp. 222, 224.

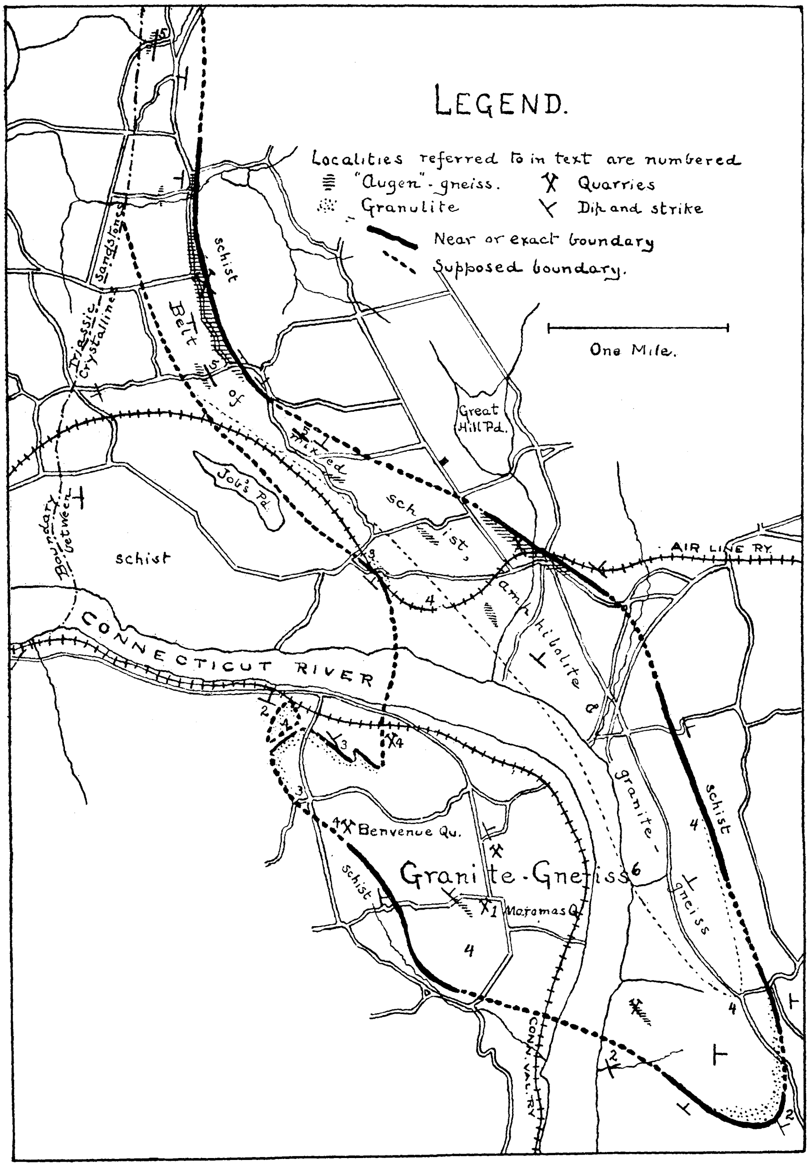

FIG. 1. Map of the Granite-Gneiss Area.

or quite parallel to the foliation, giving the rock a bedded appearance (Fig. 2. Map, 1). Several quarries have been opened, and the attempt has been made to market the rock as a building stone. It is handsome when first quarried, but stains quickly, and so is of use only for foundations, etc.

FIG. 2. Bedded Granite-Gneiss, Maromas Quarry.

I. THE GRANITE-GNEISS IS ERUPTIVE.

1. *General stratigraphical features.*—A rounded or elliptical form, like that taken by this granite-gneiss, is common in the case of eruptive granites. The narrow belt that runs into the schists from its northern end is decidedly subordinate to the larger mass of which it is an offshoot. The northwest direction of the longer axis of the granite-gneiss area is doubtless determined by the strike of the enclosing schists. The irregularity of the boundary on the west side of the granite-gneiss indicates

the same origin as does the general form of the area. At several points, too, along the western border and southern end of the granite-gneiss (Map, 2), the line of contact cuts across the strike of the foliation of the enclosing schists. This is not noticeable at all of the localities at which actual contacts between the two rocks can be seen, though it is at one or two, but it comes out on mapping the dip and strike of the schist. This foliation of the schists seems to be a stratification foliation and not a secondary structure, because (1) it is parallel to the alternating beds of schist and fine-grained micaceous gneiss which make up the schist formation, and (2) the dip and strike of the foliation is not uniform throughout the area, but varies through all possible changes.

2. *Contact Phenomena.* — At some of the localities where the exact contact of the two rocks is seen there is the clearest proof within narrower compass of the eruptive character of the granite-gneiss (Map, 3). The line of contact is frequently irregular, the granite-gneiss often cuts across the foliation of the schist or sends tongues into the schist; and sheets of schist, partly torn from the main schist mass, occur projecting into the granite-gneiss.

As the granite-gneiss occurs in the midst of completely crystalline schists, any considerable contact metamorphism of the surrounding rocks would not be expected. In many granite intrusions into crystalline rocks no contact metamorphism is seen. In the present case besides quartz, feldspar, biotite and occasionally hornblende, the schists carry at times garnet, staurolite, cyanite and tourmaline. The latter often seems to be connected with the pegmatite dikes which cut the schist. None of these less common minerals is more abundant near the contact or can be considered a result of the metamorphic action of the granite-gneiss.

It is sufficient merely to mention at this point another evidence of the igneous character of the granite-gneiss, namely, the fine-grained granulitic character which it assumes at some points about its border. This endomorphic metamorphism of the granite-gneiss will be described more fully below.

3. *Inclusions.*— One of the most striking proofs of the eruptive character of the granite-gneiss is the presence of inclusions of schist within its boundary. These are seen at a number of localities in widely different parts of the area, and commonly not far from the border (Map, 4). They vary in size from a few inches to many feet in length, and may be of linear or very irregular form. The material composing them is a biotite-schist, or a fine-grained biotite-gneiss, similar to the schist series around the gneiss and often showing the minute folding which in places is characteristic of the latter. The inclusions occur both in the more massive and in the more foliated varieties of the granite-gneiss, and also in the granulitic facies which occurs at some points about the border.

At this point it is well to describe an occurrence which, while not a proof of the igneous origin of the granite-gneiss, is best understood in connection with inclusions. At several localities in the southern half of the granite area, occur isolated bands of schist of uniform thickness, running parallel to the foliation of the immediately adjacent granite-gneiss. They cease at a greater or less distance, but their actual termination cannot be seen because of lack of outcrops. They show sharp contacts with the enclosing granite-gneiss and in one or two cases tongues of the latter enter them at a low angle, showing them to be inclusions. And as even those schist bands which do not show an apparent eruptive contact lie within an area of rock which is certainly in largest part eruptive, it is most likely that all such occurrences are inclusions. These band-like inclusions vary from a few feet to several score of feet in thickness, and are sometimes several hundred feet in length. Their direction is variable and is independent of the foliation of the schist lying nearest to them outside of the granite-gneiss area. Their sheet-like character was evidently determined by the strong foliation of the schists through which the granite-gneiss is here eruptive. It is, however, along the east side of the granite-gneiss that the amount of this foreign material is greatest. Here the mica-schist is associated with considerable dark,

thin-bedded gneiss and schist which contain both biotite and hornblende, and with amphibolite. These dark bands of gneiss and schist are not here variable in direction, but run parallel to the boundary of the granite-gneiss, and agree in dip and strike with the schist east of it and with themselves. Yet undoubted igneous contacts occur between these dark gneisses and schists, and the lighter granite-gneiss which occurs between them. The granite-gneiss which in other parts of the area replaced almost entirely the schist through which it came, here merely forced its way into fissures parallel to the foliation of the country rock. The distribution of this belt of mixed rock is shown on the map. As already pointed out the granite-gneiss gradually disappears as we go north.

4. *Schlieren.*—In a number of places where the granite-gneiss is most massive, it encloses patches of darker material or schlieren—basic segregations of the granite magma. These are best seen in the Benvenue and Maromas quarries. The schlieren are of uniform composition, finer grained than the enclosing rock, have a larger proportion of biotite, and often contain hornblende, which is almost wholly wanting in the ordinary granite-gneiss. They are rounded, elliptical or irregular in outline and always elongated parallel to the foliation so as to form lenticular patches and in extreme cases bands. This lenticular and frequently sheet-like form is probably due to movement in the partly differentiated magma previous to thes olidification of the rock. Such darker and more basic portions are very common in granites and have been regarded as a strong indication of the eruptive origin of the rock in which they are found.[1] In the Benvenue quarry where these schlieren occur, the rock also holds irregular inclusions of schist.

Associated Pegmatite Dikes.—Although the presence of abundant pegmatite dikes about a granitic area would not in itself be a proof that the rock in question was eruptive, it would be an interesting and corroborative fact. In the opinion of

[1] ROSENBUSCH: Massige Gesteine, p. 62; G. H. WILLIAMS, XV., Ann. Rept. U. S. Geol. Surv., p. 662.

Brögger,[1] Williams,[2] Crosby,[3] and others, the presence of one or more parent masses of less acid plutonic rocks is to be expected in such regions of abundant pegmatite dikes. The pegmatite dikes of central Connecticut are abundant, and are widely known for the variety and beauty of the minerals they have furnished collectors. They occur in dike-like masses in both gneisses and schists, but more abundantly in the latter, and they both cross and run parallel to the foliation of the enclosing rocks. Their contact with the gneisses and schists is sharp and they frequently contain inclusions of the same. There are two other considerable areas of granitic biotite-gneiss in the region, one to the south and the other to the north of the area under consideration. The former shows no sign of igneous origin and seems to be the basal member of a series of conformable gneisses and schists which form a northward pitching anticline. The study of the latter area is not yet completed. The evidence so far collected seems to indicate that it is largely composed of eruptive material; but even so the Middletown granite-gneiss is more centrally located with reference to the dikes and would more likely be the rock genetically connected with them. The schists which surround it are more filled with pegmatite. The hills near the Connecticut River, just west of the granite-gneiss, are known as the "White Rocks," from the prominent outcrops of pegmatite, and the schist east of the granite-gneiss is also cut by quantities of the same rock. This abundance of pegmatite dikes would lead us to expect one or more centrally located masses of granite with which they could be connected, and the area of granite-gneiss we have been describing seems to answer the expectation It does not appear that the dikes radiate from it; rather they follow in a general way the foliation of the schist. They do, however, appear to grow more abundant toward the granite-gneiss.

In connection with the evidence brought forward to show the eruptive nature of the granite-gneiss it is interesting to know

[1] Zeit. für Kryst., Vol. XIV, 1890, or Canadian Rec. Sci., Vol, VI, p. 33.

[2] Fifteenth Ann. Rept. U. S. Geol. Surv., p. 680.

[3] CROSBY and FULLER, American Geologist, Vol. XIX, p. 151.

that the granitic biotite-gneiss to the south, which has already been mentioned as constituting the lowest member of an anticlinal fold, and which appears from its field relations to be a sedimentary rock, wholly lacks the various characteristics of igneous origin possessed by the granite-gneiss. The mineralogical and structural characters which come out in a microscopical study of the rock, and which will be described below, are also in harmony with the belief that the granite-gneiss, in spite of its general and pronounced foliation, is an igneous rock.

II. PETROGRAPHY OF THE GRANITE-GNEISS

1. *The ordinary type.*—The ordinary form of the granite-gneiss is a light-colored, rather fine-grained biotite-gneiss. The amount of biotite varies considerably. Where it is most abundant, the rock is a dark-gray, well-foliated gneiss ; where least abundant, the rock is light-gray and of a quite granitic appearance. In no case does it become perfectly massive. The grain of the rock allows of its being split along the foliation into curbstones, but not, as in the case of some of the other gneisses of the region, into flagstones. In the main body of the granite-gneiss the strike of the foliation is approximately N. 45° W.; the dip, 30° N. E. Joint planes cut the granite-gneiss in several directions, one nearly or quite parallel to the foliation, others at right angles. The rock is handsome when first quarried, but has proved useless as a building stone, because it rusts on exposure.

Microscopically the rock is a granitic mixture of feldspars and quartz, in which lie small plates of biotite. The biotite is abundant, generally with a pronounced parallel arrangement, to which the foliation of the rock is due. Hornblende is almost wholly absent. In a single section green hornblende occurs in amount subordinate to the biotite and it can be seen in a very few exposures in the field. The feldspars usually present an allotriomorphic, granitic aggregate of grains. Orthoclase is most abundant. An acid plagioclase is of common occurrence. Microcline also occurs in smaller and more irregular grains.

Both orthoclase and microcline frequently show a fine microperthitic intergrowth, with a second feldspar. In a larger number of sections some orthoclase and plagioclase grains show a granophyric intergrowth, with a second mineral, probably quartz, which takes the form of narrow irregular, curving or angular inclusions, converging toward the center of the feldspar grain. This granophyric intergrowth is absent from the probably sedimentary gneisses to the south, and seems to be characteristic of those of igneous origin. Quartz occurs in irregular but somewhat rounded interstitial grains, and is also common in drop-like inclusions in the feldspars, which occasionally approach a a dihexahedral shape. Titanite, in small, rounded, and lenticular grains, is the most common accessory. A very little apatite and magnetite occur. In about one half of the sections there is evidence of a slight amount of crushing. In the section where this is best shown, some of the quartz grains have been elongated, broken into separate areas, and granulated about their border and along lines of fracture; and between the feldspar grains are lines of smaller grains, which seem to have come from the fracturing of the feldspar. Yet in this section considerable portions show no evidence of crushing, and in many slides no proof of crushing exists.

2. *Schlieren.*— The biotite-gneiss, especially where it is more massive, often contains schlieren of darker color and finer grain, which have already been referred to and partly described in the discussion of the igneous origin of the granite-gneiss. Sections from these schlieren resemble closely the ordinary granite-gneiss. They are granitic in structure, but with a distinct foliation. Green hornblende is present, but is less abundant than the biotite. Orthoclase, plagioclase, and microcline occur in abundance in the order named. A few feldspar grains show the granophyric intergrowth already mentioned. Quartz and microperthite are absent. Titanite is a common accessory. The presence of hornblende and absence of quartz, while keeping the other essential structure and characters of the granite-gneiss, indicates that these darker patches are an integral part of the

granite-gneiss, only somewhat more basic than the general rock. The absence of any evidence of crushing in the sections shows that their present lenticular and banded form was attained while the rock was still unsolidified.

3. *The "augen"-gneiss.*—Frequently the granite-gneiss becomes a decided "augen"-gneiss. Its distribution is indicated as nearly as possible on the map. It attains its best development along the northeastern border of the granite-gneiss and in the narrow tongue that runs north into the schist. The "augen"-gneiss often passes gradually into the ordinary granite-gneiss, with which it is identical in mineralogical composition and in structure, with the single exception of the occurrence of sub-porphyritic feldspar crystals and aggregates. A surface broken at right angles to the foliation shows a light gray gneiss, dotted with more or less distinct "augen" of white or pink feldspar, averaging three fourths of an inch in length, and with a parallel arrangement, around and between which run the lines of biotite flakes. The feldspar of the "augen" often reflects light as a single crystal, either simple or a Carlsbad twin, and rarely this crystal is roughly rectangular, yet it never possesses crystal boundaries. Quite commonly the cleavage surface of these broken crystals shows dull rounded areas of feldspar which are differently oriented grains included within the larger crystal. Where a single crystal occurs it forms the irregularly margined core of the "auge" and is surrounded by a dull white rim composed of an aggregate of fine feldspar grains. As the core is pink and the rim white, there is a further contrast between the two. Much more often than not, however, the reddish core does not reflect as a unit, but consists of an aggregate of grains, still flesh-colored and coarser than the rim. In other cases the "augen" consist of aggregates of white feldspars without any reddish cores.

It looks very much in the hand specimen as if those reddish cores of the "augen," which are composed of an aggregate of grains, were derived from the fracturing of single grains, which in some cases seem to remain partly intact at the center. But

where such an aggregate is examined microscopically it is seen to be composed of feldspars of different species which show no evidence of crushing. One section (Fig. 3) showed such an aggregate consisting of a very irregular Carlsbad twin of orthoclase at its center, partly or completely enclosing irregular grains of orthoclase, plagioclase, and microcline, all containing small rounded grains of quartz. There was no evidence of crushing; no evidence of derivation of the smaller grains from

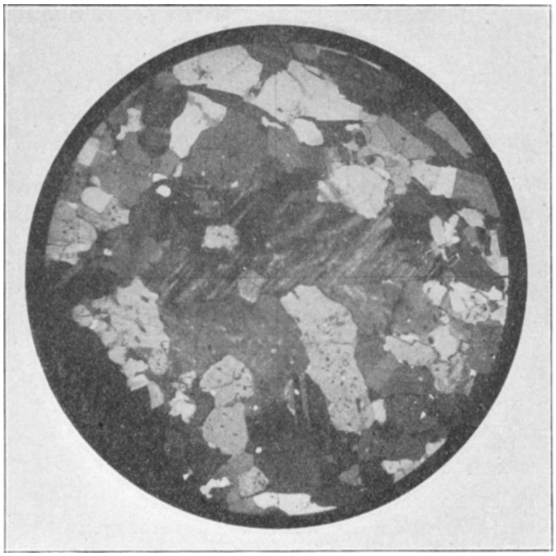

FIG. 3.— An "auge" of the "augen"-gneiss (× 18). The dark area on the upper right side is beyond the border of the section. Opposite, below, is the border of clear feldspar grains with a little biotite.

the central orthoclase grain. About this central aggregate was a zone of clearer feldspars. The red cores, then, of the "augen," both single grains and aggregates, are original crystallizations. The case may be somewhat different with the white rims which in many cases surround the red cores. These do show some evidence of crushing, and may be in part derived from peripheral crushing of the red cores, possibly accompanied by some recrystallization, for the feldspars here have a fresher appearance

than those in the central part of the "augen." Yet the absence of evidence of extensive crushing, and the fact that many of the "augen" consist wholly of white aggregates of feldspar which under the microscope show no evidence of crushing, lead us to suspect that even these white aggregates, which sometimes occur as borders around the red cores and sometimes constitute "augen" by themselves, may be, in large part, original crystallizations. The fact that these "augen" do not include to any extent plates of biotite, but that the lines of biotite flakes curve around them, seems to point to the formation of the "augen" previous to the complete solidification of the rock. The "augen"-gneiss, like the granite-gneiss of which it is a local variation, is of igneous origin. If we suppose that the first step in its formation was the separation of small orthoclase individuals or aggregates of feldspar, mainly orthoclase, but containing plagioclase and microcline, which received their parallel arrangement before the final solidification of the rock, and which may have been subsequently somewhat reduced by crushing, we shall have the most probable explanation of the "augen"-gneiss phase of this granite-gneiss.

The foliation of the granite-gneiss does not seem to be in the main a dynamic result. Evidence of crushing is found in many sections in the form of wavy extinction of the quartz and lines of finer material between the larger quartz and feldspar grains, and crushing may be responsible in part for the parallel structure of the rock. Yet in many sections of the well-foliated gneiss the microscope shows no evidence of crushing at all. It seems more likely that the arrangement in a common plane of the biotite and, in the "augen"-gneiss, of the often rather tabular grains of orthoclase is a result of movement in the partly solidified magma. The character of the schlieren points to the same conclusion. In ordinary granites the schlieren are not stretched, but are roughly equidimensional, and such we may suppose their original form to have been in the present case. Had they been drawn out to their present distorted condition subsequent to the solidification of the rock, they could hardly

fail to show evidence of such a movement in the distortion and crushing of their individual mineral particles, but such is not the case. And a rock subjected, while still incompletely solidified, to such an extensive movement as is indicated in the present instance by the form of the schlieren, would naturally have the elements which had already crystallized out, in this case biotite and, locally, individual grains and aggregates of feldspar, arranged in a more or less parallel manner.

4. *Granulite.*—For a mile along its western border, and for a somewhat greater distance about its southern end, the granite-gneiss shows a granulitic facies towards the contact. At other points both the "augen"-gneiss and the ordinary granite-gneiss may occur unchanged in immediate contact with the schist. The width of this granulite border is not constant; it varies from two or three feet to many yards. Where typically developed, it is a fine-grained, light gray or brownish rock, sometimes pure white and lacking all traces of dark minerals. This pure white granulite is present only at a few places and immediately at the contact. Small garnets are usually present. The rock has asugary texture, and when somewhat weathered often crumbles under the pressure of the fingers. Microscopically it is a fine-grained aggregate of orthoclase, an acid plagioclase, microclineand quartz. The structure is the so-called granulitic of M. Levy[1] and the panidiomorphic of Rosenbusch.[2]

The quartz and feldspar form an aggregate of variously oriented rounded grains of uniform size, which are not, however, bounded by crystal planes. With the scarcity of biotite, the foliation becomes indistinct or wanting. In one case garnet grains form fine lines on the broken edge of the rock. No evidence of crushing exists.

[1] M LÉVY: Classification des Roches Éruptives, p. 30.

[2] ROSENBUSCH: Massige Gesteine, p. 461. In this connection see TURNER: Geology of the Sierra Nevada, Sixteenth Ann. Report U. S. Geol. Surv., Pt. I, p. 737. Granulite (M. Lévy) is synonymous with aplite (Rosenbusch). Rosenbusch regards aplites as typically dike rocks, yet recognizes their occurrence as acid border phases of granite intrusions. *Ibid.*, p. 65.

At several localities the granulite can be followed from the contact and can be seen to pass gradually into the ordinary granite-gneiss. The changes on passing from the contact are as follows: (1) The rock becomes coarser, loses its granulitic structure and assumes a granitic structure. (2) The garnet disappears, biotite becomes abundant and is accompanied by the ordinary accessories of the granite-gneiss, titanite, magnetite and apatite. (3) Small grains of granophyre and microperthite

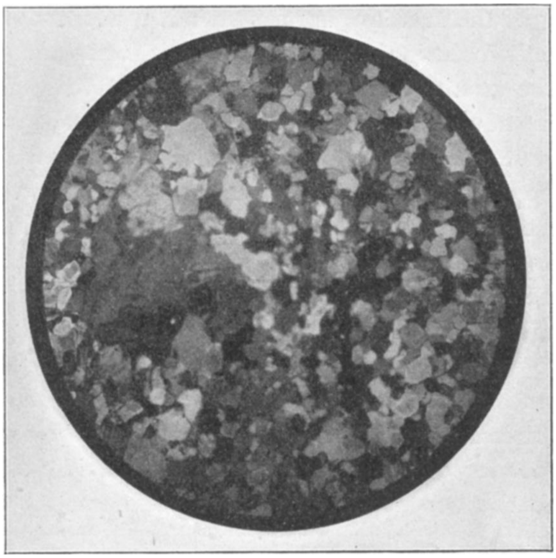

FIG. 4. Granulite (×18).

appear. These are common among the feldspars of the granite, but are wholly lacking in the granulite. Of these characters the granulitic structure and the presence of garnet extend farthest from the contact and often at a distance of many yards the richly biotitic granite-gneiss becomes garnetiferous and shows a decidedly saccharoidal texture.

Bands of granulite occur interbedded with or cutting across the schists near the contact. These bands are often less than an inch in thickness, and may connect with the main mass of the

granulite. A few of the smaller bands contain much muscovite and are well foliated. The granite-gneiss sometimes assumes a granulitic facies about inclusions. A good example of this occurs at one end of the Benvenue quarry, west of the river. A fifteen-foot mass of schist is caught in the granite-gneiss, which is dark gray and thick-bedded, but at the contact with the schist-inclusion changes to a fine-grained, white granulite with minute scattered flakes of biotite.

The eruptive nature of the granulite is clear. It cuts across the bedding of the surrounding schists ; it sends apophyses into them ; it holds inclusions of them. That it forms one geological body with the granite-gneiss is shown by its gradual passage into the latter at several points. It is not a crushed granite, as its position about the border of the granite and the absence of any microscopical evidence of crushing would show. It is an example of original endomorphic contact-metamorphism of the granite-gneiss,—more acidic and finer grained than the main body of the rock. The fineness of grain and the granulitic structure may be due to more rapid cooling of the magma in the neighborhood of the contact, though there is no reason why the conditions and consequently the structure of the granite-gneiss should be different at these points from what they were about the whole border of the granite. The more acidic character of the rock at the contact has not been satisfactorily explained. Similar phenomena have been observed elsewhere,[1] notably about some of the granite intrusions of France.

Besides the contact granulite described above, granulite occurs in three distinct forms. It occurs (1) as bands, generally not over a foot in thickness, cutting the granite-gneiss in or across the foliation and often becoming coarser and somewhat pegmatitic. In many cases these bands appear to grade somewhat abruptly into the surrounding rock. They are in a sense later than the granite wall-rock and may mark a closing stage of igneous activity, before the granite had fully hardened. It

[1] ROSENBUSCH, Massige Gesteine, p. 65. References to articles by BARROIS on several of these granites are given on p. 14.

occurs (2) as a white, fine-grained granulitic portion of some of the pegmatites. (3) One or several dikes of gray granulite cut the dark gneisses which occur associated with the granite-gneiss along its northern border (Map, 5). Their position is shown on the map. Each of these varieties has its own peculiarities and all differ from the contact granulite. They are probably all later than this last and are merely mentioned here for the sake of completeness.

5. *Darker and more foliated granite-gneiss.*—Along the north-eastern side of the granite-gneiss area is a belt which has already been noticed, in which the granite-gneiss alternates with schists and with dark, more or less hornblendic gneisses and amphibolites. This area is indicated on the map. Associated here with the granite-gneiss and with these other rocks is a third type, in a way intermediate, yet more closely related to the granite-gneiss. These last rocks are darker and more foliated than the granite-gneiss. They are frequently marked by lenticular-linear white patches, up to a third of an inch in thickness, composed of an aggregate of feldspar grains. From this character they may be named "spotted-gneiss." They agree microscopically in structure and in mineral composition with the granite-gneiss. There are only two differences: (1) an increase in the amount of biotite and, as a consequence, a better developed foliation, and (2) the presence in some cases of hornblende. Sometimes they show microscopical evidence of crushing. They form eruptive contacts with the schists which are cut by the granite-gneiss.

The relations of the spotted-gneiss and the amphibolites are not wholly clear, and these relations are probably different in different cases. The two rocks are distinct petrographically. The contact between the two is an eruptive contact. If the amphibolites are older—and their stronger banding and foliation might well suggest as much—it matters not to the understanding of the granite-gneiss whether they are of igneous or sedimentary origin; they are in either case earlier rocks cut by the granite-gneiss. But in many cases they are probably later.

For eruptive amphibolites occur abundantly in the schist and presumably sedimentary gneisses outside the granite-gneiss area, and at one point within the granite-gneiss (Map, 6) banded amphibolites occur grading into massive hornblende-gabbro, and this basic rock becomes finer grained toward the contact where it cuts across the foliation of the granite-gneiss. Some of these amphibolites, then, are certainly younger than the granite-gneiss and cut it. Some may be older than the granite-gneiss.

The relation of the spotted-gneiss to the more ordinary granite-gneiss is not altogether clear. In some cases parallel bands of the two lie in sharp contrast. Again within limited areas a complete series of intermediate rock types occur. The spotted-gneiss seems to be a somewhat more basic rock derived from the same magma as the granite-gneiss. In part, however, it looks as if the two were not strictly contemporaneous. The spotted-gneiss may have been intruded into the granite-gneiss, or *vice versa*, although both find their origin in the same molten body and were the products of a single igneous intrusion.

LEWIS G. WESTGATE.